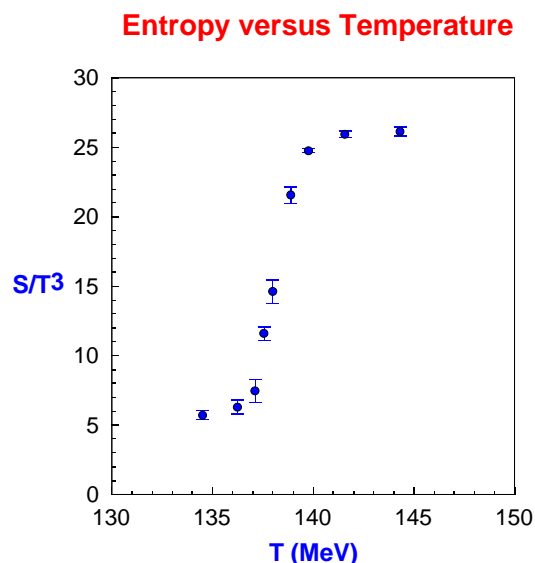


## The QCD Phase Transition and the Quark Gluon Plasma

- As the vacuum is heated above  $\approx 150$  MeV a change of phase occurs:
  - Quarks and gluons bound in conventional hadrons boil free.
  - Chiral magnetization, the origin of 99% of the known mass in the Universe, disorders.
  - A state of matter is created that last existed 100 picoseconds after the Big Bang.
- Objective of RHIC experimental program.
- Lattice QCD allows the *ab initio* theoretical study these phenomena.



## Computational Difficulties

- Fermion formalism must respect chiral symmetry.
  - For staggered or Wilson fermions, the limit of vanishing lattice spacing is essential.
  - Other more computationally demanding improvement schemes may work: clover-improved? fat links? domain wall fermions?

[Complicated actions and operators.]

- Small quark masses are essential.
  - Critical, second-order behavior expected only as  $m_{\text{quark}} \rightarrow 0$ .
  - Physical  $u$  and  $d$  quarks are very light.

[Inversion of poorly conditioned matrices.]

- Large volume needed for the thermodynamic limit.  
[Critical slowing down.]

- A large range of parameters must be studied to determine equation of state.

## Present State-of-the-Art

- Most simulation performed with staggered fermions.
  - Coarse lattice spacing,  $a=0.25$  Fermi.
  - Large lattice-induced chiral symmetry violation.  
*E.g.* two of the three pion species are heavy,  
 $m_\pi \approx 600$  MeV, compared to 140 MeV in Nature.
- Promising exploration of improved algorithms:
  - Improved action brings high temperature much closer to expected Stephan-Boltzmann behavior.
  - Fat-link Dirac operator reduces the heavy pion masses in the quenched approximation.
  - Domain wall fermions promise chiral behavior for coarse,  $N_t = 4$  lattices with  $L_5 = 48$ . [This is now an on-going production calculation at  $\approx 50$  Gflops sustained.]

## SSI Goals for QCD Thermodynamics

Determine lattice spacing dependence of  $T_c$ , character of the transition and equation of state using domain wall fermions and an improved gauge action.

- Extend current  $16^3 \times 4$  work and decrease lattice spacing by 50%, using a  $24^3 \times 6$  lattice.
- Estimate of required resources:
  - Present  $16^3 \times 4$ ,  $L_5 = 48$  calculation requires  $\approx 2 \cdot 10^{14}$  flop/update, or 0.1 Tflops year for a required 20,000 updates.
  - Since required flops scales as  $(1/a)^{10}$ , but the needed  $L_5$  may decrease by  $2\times$ , this scales to 2.5 Tflops year.
- This is an appropriate project for a lattice QCD SSI effort in the third or fourth year of the SSI program.

Examine improved Wilson fermions on an  $32^3 \times 8$  lattice.

- Part of algorithm development effort.
- Scaling from 0.1 Teraflops year estimate above, introduces a factor  $2^{10}/48$  or again about 2 Teraflops year.